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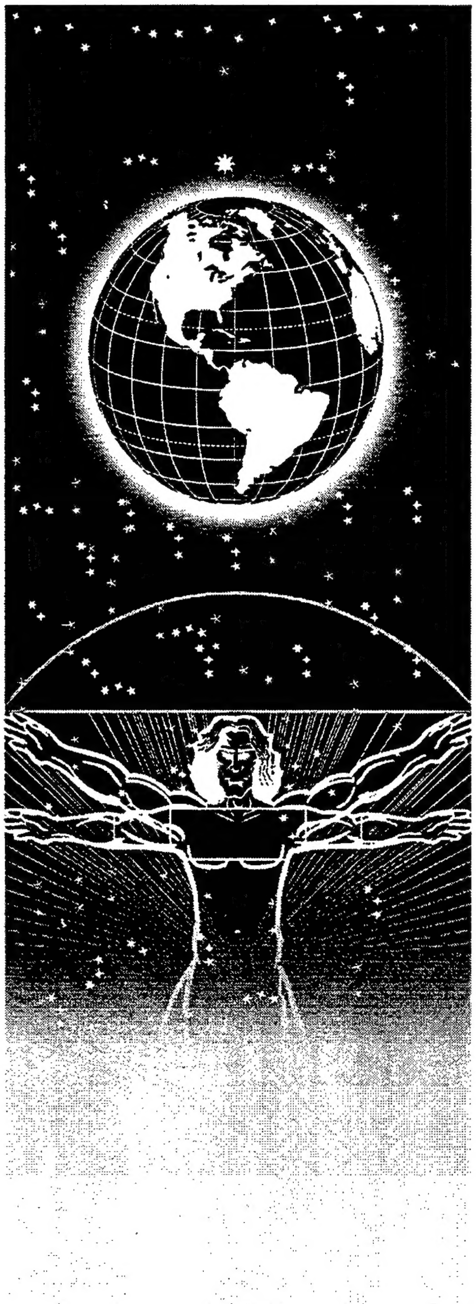

UNITED STATES AIR FORCE
IERA

Remedial Action Workplan, 1964 B-58 Accident Site, Grissom Air Reserve Base, Bunker Hill, Indiana

Steven E. Rademacher, Major, USAF, BSC

August 2000

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13. ABSTRACT *(Maximum 200 words)*

On December 8, 1964, during a routine Operational Readiness Inspection, a B-58 strategic bomber skidded off the runway at Bunker Hill AFB, IN (later named Grissom Air Force Base). The consequence of the accident was a fire and destruction of five nuclear weapons on the aircraft. The high explosives in the weapons did not detonate, but melted and burned, leaving some residual radioactive contamination in soils adjacent to the runway. The contaminated area was excavated and buried along with the aircraft wreckage at a different location on base. In 1999, AFIERA performed a radiological characterization of the site (IERA-SD-BR-TR-2000-0002). The results of the survey confirm that a small area of the site investigated contains depleted uranium contamination. The investigation area was about 8,800 square meters and had an estimated excess surface activity concentration of 1 pCi/g averaged over the entire area. Within this area, the contamination zone is limited to an area of 1000 square meters, with a mean excess uranium activity concentration of 7 pCi/g. This report details a remedial action plan for the site. The remedial action work plan details tasks to be accomplished by AFIERA and a private contract organization. Included in the plan are details on 1) pre-remediation site survey, 2) soil removal activities, 3) remedial action support surveys, 4) final status soil sampling, and 5) soil backfill of the remediation area.

14. SUBJECT TERMS
depleted uranium, nuclear weapon, Air Force, radiological remediation, Broken Arrow, Bunker Hill AFB, Grissom AFB, Grissom ARB

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Table of Contents

List of Figures

List of Tables

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1. Introduction

a. Purpose. The purpose of this report is to present the remedial action work plan for the B-58 crash site. The plan describes pre-removal soil survey, soil removal operations, remedial action support survey, and final status survey plans. The actions described in this report are limited to the contaminated site in a grassy area alongside NE-SE Runway 23. This site was contaminated by a nuclear weapons accident that occurred 8 December, 1964 when a B-58 strategic bomber skidded off the runway. The B-58 wreckage and some contaminated soils were buried at another location. Investigation and remediation of the burial site is described in other documents.

b. Site Description. The crash site is alongside NE-SW Runway 23 (Figures 1 and 2). The area is bounded by a concrete runway or taxiways, and contains aircraft navigational aids and a

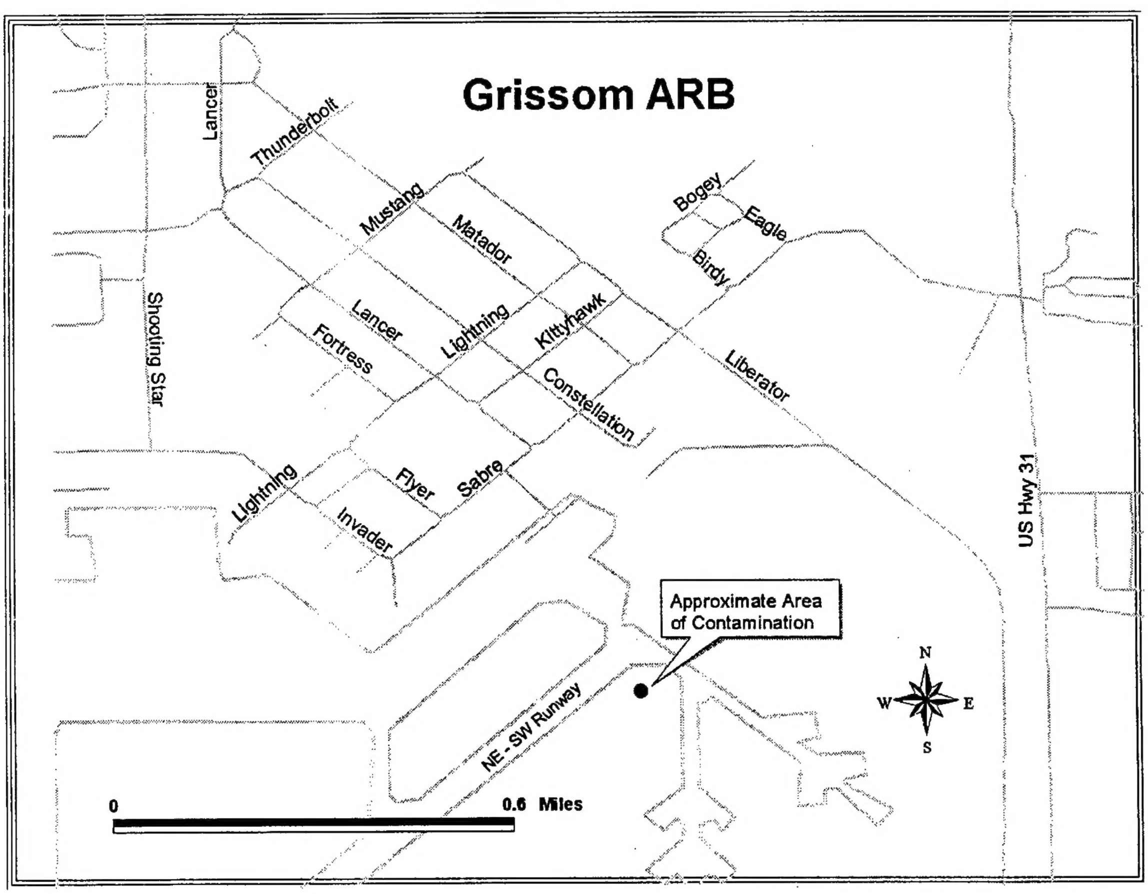


Figure 1: Site Location and Surrounding Area

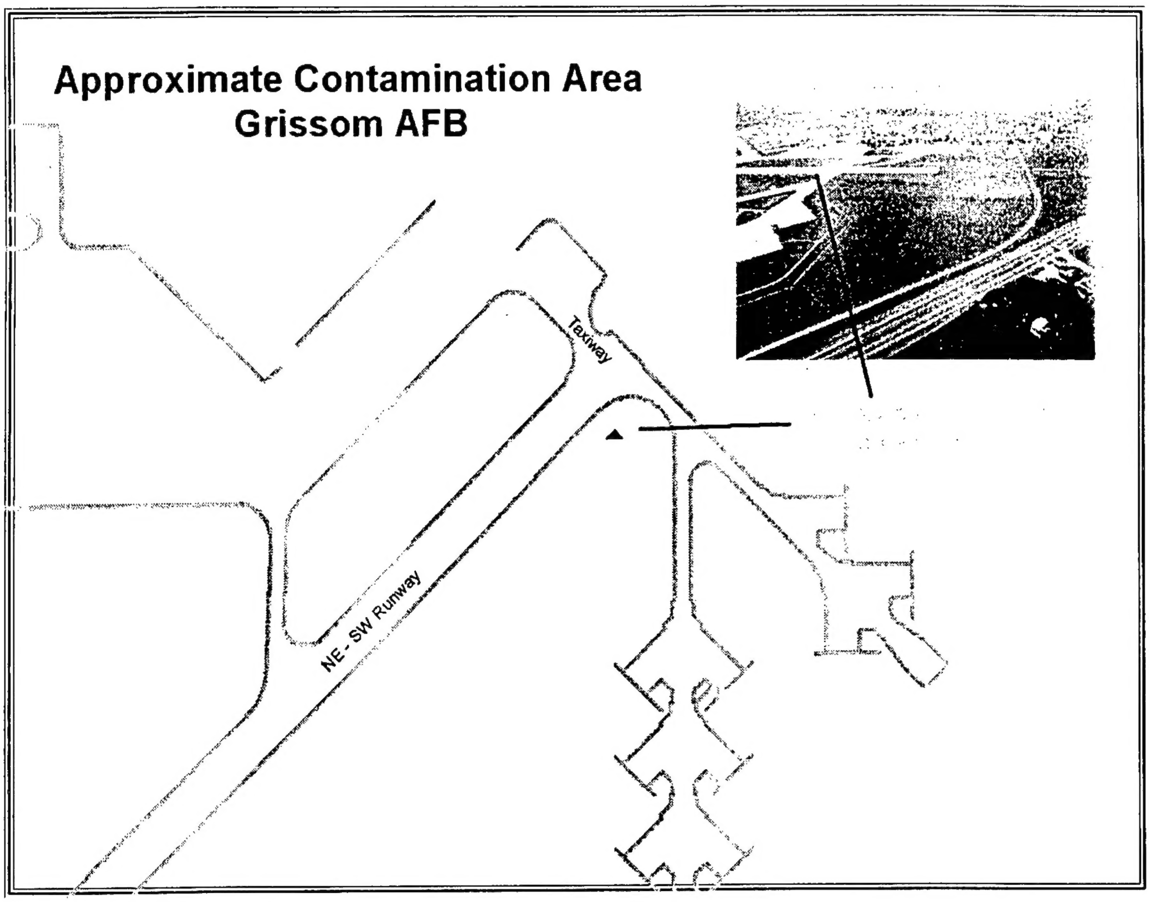


Figure 2: Site Location

windsock in its center. The vegetation consists of native grasses that are mowed on a regular basis to height of less then 15 cm (0.5 ft). The terrain is relatively flat but is marked by irregularly spaced depressions less then 30 cm (1 ft) deep. Approximately 50 m (160 ft) southwest from the windsock, a drainage ditch is terminated in a culvert. Due to its close proximity to active flight operations, access to the site is tightly controlled. Grissom Air Force Base was realigned under the Base Realignment and Closure Commission and was renamed Grissom Air Reserve Base (ARB); however, it still maintains an active flying mission, with the Air Force Reserve's 434th Air Refueling Wing (ARW). The 434th ARW is equipped with 22 KC-135 Aircraft and 1300 personnel. There are currently no plans to relinquish Air Force control of the area planned for remediation.

c. Summary of Proposed Actions. The proposed actions include five distinct phases. 1) A pre-remediation site survey will locate the contamination zone described in previous surveys and delineate the proposed remediation area. 2) The remediation area will have soil removed in a one-foot lift. 3) The site will be scanned to locate areas of residual contamination. Identified areas will have another one-foot lift. The previous procedure of scanning will be accomplished with associated

additional soil removal until the identified area has residual contamination below the scanning capabilities of the portable detection instruments. A detailed remedial action support survey will be accomplished with fixed in-situ gamma measurements. If areas with contamination are identified above the action level for the portable gamma instrument, additional soil removal will be accomplished. 4) Soil sampling will be accomplished at the remediation and surrounding area to assess the final status of the site. 5) Soil will be back-filled in the remediation area.

2. Historical Site Assessment

a. Historical Record of Accident

On December 8, 1964, during a routine Operational Readiness Inspection, a B-58 strategic bomber skidded off the runway at Bunker Hill AFB, IN (later renamed Grissom Air Force Base). The landing gear subsequently collapsed, rupturing a fuel tank. The ensuing fire burnt portions of the five nuclear weapons on board the aircraft. The high explosives in the weapons did not detonate, although some portions melted and burned (Sandia 97). One weapon that caught fire was removed from the accident area, and extinguished by placing it in a shallow trench and covering it with sand. The trench was located approximately 50 m (160 ft) from the aircraft wreckage in the grassy area between the runway and alert area taxiway. The precise location of the trench is unknown from the historical record. The historical record indicates radioactive contamination was confined to a 2 m x 6 m x 10 cm (7 ft x 20 ft x 4 inch) volume (HQ Air Force Safety Center 96). The contaminated soil around the aircraft wreckage was excavated and buried along with the aircraft debris at a different location on the base. Extensive sampling of the area soon after the accident was said to have demonstrated that the area was contamination free. Written documentation of the post accident sampling has not been located. Additionally, the instrumentation available at the time of the accident (primarily alpha scintillation and Geiger-Mueller detectors) coupled with the wet conditions questions sufficiency of delineation of residual contamination with respect to present standards.

The recovered weapons and weapons debris were sent to Atomic Energy Commission facilities in Clarksville, TN; Medina Base, TX; Rocky Flats, CO; Miamisburg, OH; and Oakridge, TN. (Sandia 97). Subsequent analysis of the damaged weapons and debris indicated that plutonium was not released to the environment because all of the plutonium bearing components were intact (Rademacher 99a).

In June of 1996, the Air Force Safety Center, at the request of Grissom ARB, conducted a review of both the classified and unclassified documents in its possession and concluded that sufficient data did not exist to support unrestricted release of the site (Headquarters Air Force Safety Center 96).

b. Scoping Surveys. The Indiana State Department of Health (IDH) performed gamma exposure rate measurements and collected soil samples from the accident site. The IDH identified a small area with γ-radiation exposure rates eight to ten times background rates. Soil samples collected from this area contained concentrations that were several hundred times background for ^{238}U. ^{235}U and ^{234}U concentrations were also elevated in proportion to that of depleted uranium, with the highest total uranium activity concentration over 700 pCi g^{-1}. Plutonium concentrations were consistent with levels typical of background (EPA 96). The Air Force Institute for Environment, Safety, and Occupational Health Risk Analysis (AFIERA) conducted a scoping survey in May 99 and collected five soil samples that through laboratory analysis had the signature of depleted uranium, with the highest total uranium activity concentration of 95 pCi g^{-1}.

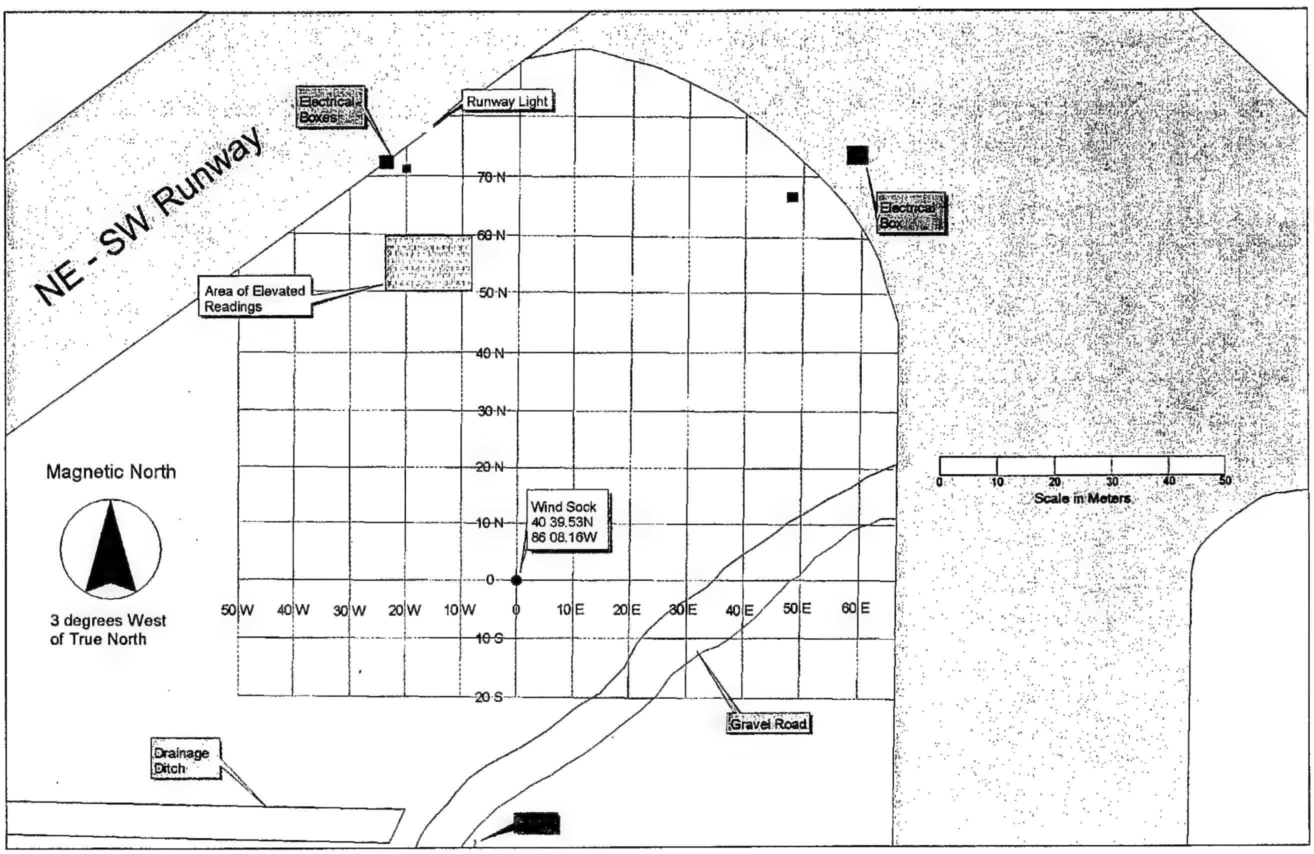
3. Characterization Survey

a. Survey Results.

AFIERA performed a comprehensive site characterization in October 1999 that consisted of both fixed and scanning in-situ gamma measurements, and extensive soil sampling (Rademacher and Hoak 00). The survey evaluated an 8800 m^2 (95,000 ft^2) land area in square grids of 100 m^2 (1100 ft^2). The scanning survey identified only one area of elevated contamination as shown by the pink box on the site grid of Figure 3. The pink box roughly encompasses 300 m^2 (3200 ft^2) and has a mean excess total uranium (i.e. not attributed natural background sources) surface activity concentration of 15 to 20 pCi g^{-1} (Rademacher and Hoak 00). Figure 4 provides a more detailed map of the contaminated area and contains notation of the mean surface soils sampling results (^{234}Th) for each grid shown in the map and fixed in-situ gamma measurements in the hot-spot location. ^{234}Th is typically used to quantify uranium because it is in the decay chain of ^{238}U and has an abundant gamma emission. The pink rectangular box is similar in placement to that in Figure 3. For the 10 grids with mean surface ^{234}Th activity concentrations greater than 2 pCi g^{-1}, the mean excess uranium activity concentration is about 7 pCi g^{-1}. Chemical analysis of targeted soil samples had beryllium concentrations typical of background. ^{241}Am activity concentrations were below the

minimal detectable concentration (MDC) [varied from 0.03 to 0.21 pCi g^{-1} among samples analyzed] for the gamma spectroscopy measurement system. ^{241}Am is the daughter of ^{241}Pu and a co-contaminant of weapons grade plutonium (WGP). Based on other sites contaminated with WGP from the time period of this accident, the $^{239/240}$Pu to ^{241}Am activity concentration is about 5.4 (Rademacher 99b), making the highest individual sample $^{239/240}$Pu MDC about 1.1 pCi g^{-1}.

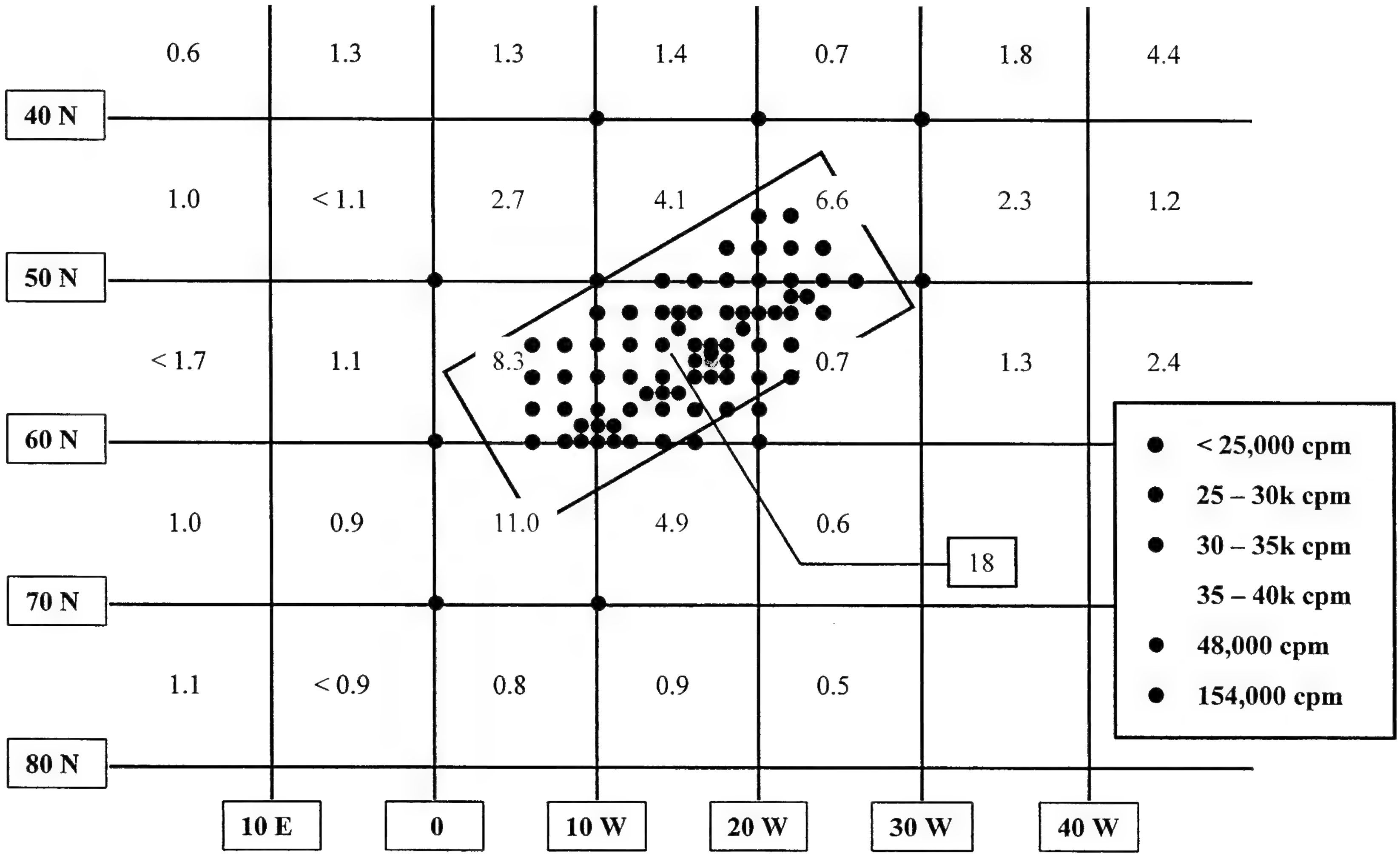
Figure 3. Site with Contaminated Area Denoted by Pink Rectangular Box.



b. Contaminants of Concern

Based on the results of the latest characterization study conducted by AFIERA, the only contaminant of concern is depleted uranium (natural uranium depleted in ^{235}U and ^{234}U isotopes). Uranium, a naturally occurring radioactive element, is silver-white in its pure form. It is a heavy metal nearly twice as dense as lead (19 g cm^{-3}). Uranium occurs in nature in a wide variety of solid, liquid, and gaseous compounds. It readily combines with other elements to form uranium oxides, silicates,

Figure 4. Fixed In-Situ Gamma Measurement Results for Hot-Spot Area and Accompanying Mean Grid Surface Soil Sampling Results for ^{234}Th (pCi/g) – Grid in Meters



carbonates and hydroxides. These compounds range from being highly mobile (soluble) to being relatively immobile (insoluble) in the environment.

Uranium metal alloys are readily machinable and have metallurgical properties similar to those of high-strength steels. Finely divided uranium metal is pyrophoric (i.e., burns spontaneously in air). Table 1 contains the isotopic composition of natural and depleted uranium. Table A-1 of Appendix A provides a partial list of nuclides and their emissions from the ^{238}U decay series. The ^{235}U decay series is shown in Table A-2 of Appendix A.

Table 1. Characteristics of Natural and Depleted Uranium

Material	Component by Weight Percentage				Specific Activity ($\mu Ci\ g^{-1}$)
	^{234}U	^{235}U	^{236}U	^{238}U	
Natural U	0.0057%	0.72%	0%	99.28%	0.7
Depleted Uranium	0.0001%	0.20%	0.0003%	99.8%	0.4

c. Gamma Measurements. ^{234}Th is the most readily quantifiable short-lived daughter of ^{238}U as measured in gamma spectroscopy systems. For gamma spectroscopy measurements of the soils collected from the AFIERA characterization study, the highest MDC for those samples with activity concentrations below the MDC was 1.8 pCi g^{-1}. This result was from a surface sample collected in a grid with surface activity believed to be at background levels. Samples with depleted uranium contamination will have higher MDCs due to higher count rate in the Compton continuum of gamma spectroscopy spectra. ^{235}U emits a 0.185 MeV γ-ray with a percent yield of 57 %. This nuclide has a MDC about one-tenth that of ^{238}U (Rademacher and Hoak 00).

d. Fixed In-Situ Gamma Measurements. Fixed in-situ gamma measurements were performed with a 3 x 3 inch NaI(Tl) detector in the gross detection mode with the detector lower surface 10 cm above the ground surface. The mean count rate in the background measurement area was 22,676 counts per minute (cpm), with a standard deviation of 631 cpm. For one-minute count times, about 94 % of total variance is attributed to background variability and 6 % to random counting statistics under the assumption that these are the only sources of variability. For 30-second

count periods, the distribution of variance among the two factors is 89 and 11 %, in the order as given above. For 15-second counting periods, the distribution is 78 and 22 %.

4. Methodology

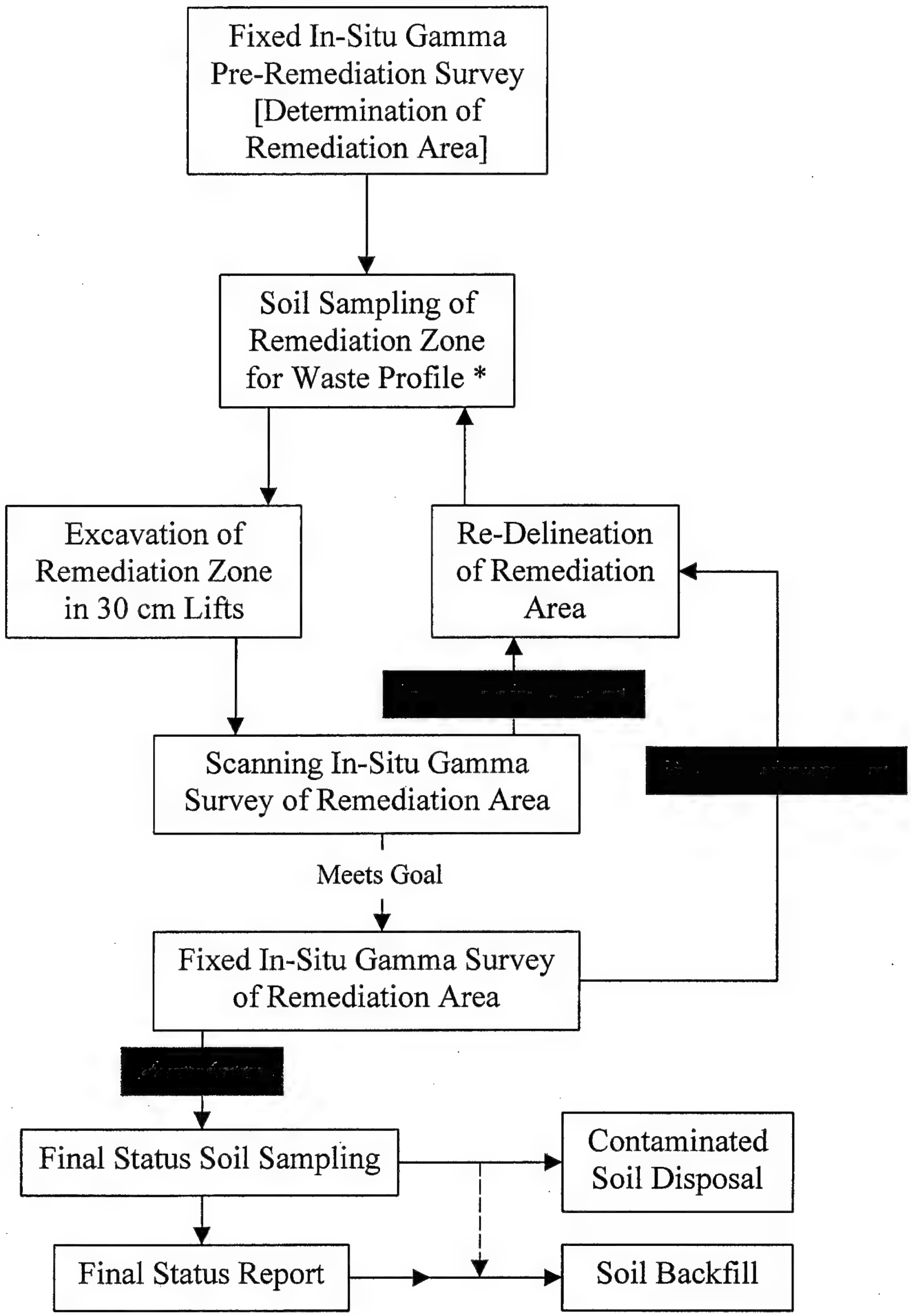
a. General. The methodology described in this work plan delineates remediation areas based on discrimination of contaminated areas from background areas using a portable 3 x 3 NaI(Tl). Areas with low-levels of depleted uranium contamination that are not readily differentiated from background radiation areas, will be left as residual. This method reasonably balances contaminated waste disposal costs, remedial activity survey time, equipment and personnel costs, and mobilization costs. Reduction of downtime in the course of the remedial activity reduces the overall costs of the project. The use of portable field instruments to assess soil removal requirements is highly advantageous over soil sampling and subsequent laboratory analysis, because of the time lag between collection and completion of sample analysis. Figure 5 provides a conceptual flow of the site survey, remedial activities, and final status survey. AFIERA and a private contract organization will accomplish the work. AFIERA will perform site survey work, final status survey and waste characterization soil sampling, and final status site survey. The private contract organization will accomplish soil removal, packaging, brokering of the waste, and transportation to an appropriate disposal site. The 434th CES/CEV will coordinate site access and staging areas for contaminated soil, clear the remediation area for digging activities, and approve soil remediation termination and site backfill. Brokering and disposal will be coordinated with the Air Force Radioactive Waste Office.

b. Pre-Remediation Survey.

General. The pre-remediation survey will delineate the area planned for remediation. The initial rough delineation of the area will be accomplished by scanning measurements with a 3 x 3 NaI(Tl) and re-establishment of the grid noted in Figures 3 and 4. Fine delineation of the area will be accomplished with fixed in-situ measurements using the same detector.

Correlation Coefficient from AFIERA Characterization. Sensitivity of the portable instrument to the depleted uranium contamination is based on measurements from the characterization (Rademacher and Hoak 00) as described in Appendix B. Of the two methods described for estimation of the correlation coefficient, the one yielding the lower coefficient had a

Figure 5. Site Remediation and Final Status Survey Procedures



* May Be Alternatively Accomplished when Soil Intended for Disposal is Prepared for Disposal

value of 200 pCi g^{-1}. This value will be used for other calculations listed in this report and during remediation activities.

Fixed In-Situ Measurements. For this action, a background assessment will be re-accomplished in the area used in the characterization study for background determination. A plot similar to that of Figure B-1 will be developed. The count rate corresponding to the 5 % inverse cumulative probability level will be used to delineate the remediation area based on fixed in-situ measurements of 30-seconds. Based on the data from the characterization study and Figure B-1, the delineation of the remediation area is estimated to correspond to 6.4 pCi g^{-1} excess total uranium. If the instrument response varies significantly from that observed in the characterization study, adjustments in the action level will be made with the approval of the 434^{th} CES/CEV. Fixed in-situ measurements will be collected on a 2 meter (6.6 ft) grid with the total number of measurements expected to be about 150.

c. Soil Sampling of Remediation Zone for Waste Characterization. Soil sampling can be accomplished prior to soil removal operations or on the removed soils in the transportation containers. The sampling method chosen will be based on requirements of the waste disposal facility, waste broker, and operational requirements of the private contract organization. Sampling is anticipated to require a minimum of one sample per transportation container and a minimum of 10 for the waste being disposed.

d. Soil Removal Operations. The private contract organization will perform all soil removal and packaging operations. Soil will be removed from the designated area in 30 cm (1 ft) lifts. Of the soil samples collected at depth during the characterization study (Rademacher and Hoak 00), none of the samples at depths greater than 30 cm (1 ft) had excess total uranium concentrations greater than the screening level of 6.4 pCi g^{-1}. As such, the first 30 cm (1 ft) lift is expected to be effective in meeting the remediation goal.

e. Scanning In-Situ Gamma Screening Survey. AFIERA will accomplish a scanning in-situ gamma screening survey of the remediation area. The purpose of the survey is to identify locations with residual contamination above the screening level of 20 pCi g^{-1}, with the probability of 5 % of falsely identifying uncontaminated areas (see Appendix B, Figure B-2). The entire remediation area will be scanned with the portable 3 x 3 NaI(Tl) at a rate of 0.25 m s^{-1} (0.8 ft s^{-1}) with the instrument

bottom surface being held about 6 cm (2.5 in) from the ground. An "S" pattern motion will be used for the survey with the instrument set to integrate over two seconds. A flag will mark areas failing to meet this screening criterion. Random location of the flags will be interpreted as areas not requiring further consideration, while a cluster of flags will be interpreted as areas of residual contamination potentially requiring further remedial action. Consultation with the 434th CES/CEV concerning the results of the survey will be made to determine additional remediation needs as noted in the procedural diagram of Figure 5. If further remedial actions are not deemed unnecessary at this point, a fixed in-situ gamma survey will be accomplished.

f. Post-Remediation Fixed In-Situ Gamma Survey. AFIERA will conduct a post-remediation fixed in-situ survey with the 3 x 3 NaI(Tl). Survey methodology will be the same as the pre-remediation survey. Individual survey point measurements will be compared to the criterion from the plot prepared earlier in the remediation project based on the background region (i.e. Figure B-1, but with current measurement data). Individual measurements exceeding the 2.5 % inverse cumulative probability will be marked for further investigation. Some modifications to this criterion may be required. Because post-remediation measurements will be collected in an excavated area, the response of the survey instrument to background conditions will be higher than for level grade. This effect should be more pronounced in areas with deeper excavations and near edges of the excavated area. There may be a slightly higher instrument response in areas with bare soil compared to the background area that will have grass. A plot of the survey area will be generated with notation of the survey points having measurements in excess of the 2.5 % inverse cumulative probability. The distribution of measurements will be compared to those from the pre-remediation survey and in-situ gamma measurements from the background area. A cluster of measurements in excess of the 2.5 % inverse cumulative probability would be indicative of residual contamination. Consultation with the 434th CES/CEV concerning the results of the survey will be made to determine additional remediation needs as noted in the procedural diagram of Figure 5.

g. Summary of In-Situ Survey Data and Remediation Criteria. Table 2 contains a summary of the in-situ survey data used to delineate the remediation area, screening levels, and recommended actions. The approach is designed to allow excavation of the vast majority of soil based on the pre-remediation survey, reduce the inactive time for the heavy equipment/crew, and limit disposal of soil with activity concentrations below the estimated screening level of 6.4 pCi g^{-1}.

Table 2. In-Situ Survey Data and Remediation Criteria.

Survey Stage	Measurement	Screening Level	Action
Pre-Remediation	Single Fixed In-Situ Measurement	5 % Inv. Cum. Prob. (~ 6.4 pCi g^{-1})	Remediate Area
Post-Remediation	Scanning In-Situ	5 % Inv. Cum. Prob. (~ 20 pCi g^{-1})	Flag Locations in Excess – Evaluate for Clusters – Consider Remediation
Post Remediation	Single Fixed In-Situ Measurement	2.5 % Inv. Cum. Prob. (~ 8 pCi g^{-1})	Flag Locations in Excess – Evaluate for Clusters – Consider Remediation
	Fixed In-Situ Measurements	Population Statistics – Mean Residual	

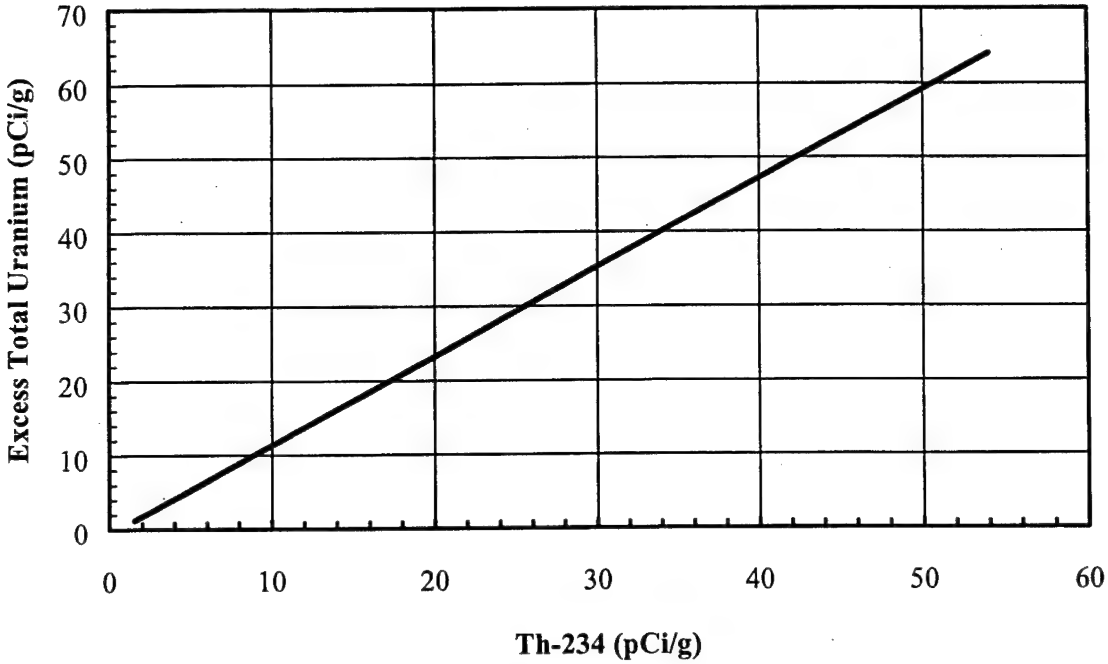
h. Final Status Soil Sampling.

A sampling grid will be developed using the reference grid system implemented in the characterization study (Rademacher and Hoak 00). The sampling grid will encompass the entire remediation area and an approximately equal area surrounding it. Twenty-five surface soil samples will be collected using a triangular grid system according to the method described in the Multi-Agency Radiation Survey and Site Investigation Manual (NRC 1997). Soil samples will be a composite of four sub-samples collected from the selected areas.

Sampling depth will be approximately 15 cm (0.5 ft) with each composite sample comprising approximately one kilogram (kg). The samples will be collected with a small shovel, with decontamination between each sample using distilled water. Samples will be containerized in one-gallon screw-top HPDE soil jars (NSN 8125-01-227-6038). The sample jars will be wiped with a damp cloth prior to packaging to remove exterior contamination. The container lids will be sealed with tape and packaged in partitioned cardboard boxes. Chain of custody will be documented on a chain of custody form with specific sample data recorded on an AF Form 2753, *Radiological Sampling Data*. To maintain chain of custody, all samples will be under constant observation or secured. All sample labels will be completed using waterproof ink.

The samples will be dried, homogenized, and analyzed through gamma spectroscopy. An estimate of excess total uranium will be made through analysis of the ^{234}Th and the relationship of Figure 6.

Figure 6. Excess Activity Concentration of Total Uranium vs. Measured ^{234}Th for Background Total Uranium = 1.1 pCi g^{-1}.



i. Waste Profiling Sample Analysis. Samples collected for waste profiling will be analyzed for radiological content, volatile chemicals, and metals. Other analyses will be performed is required by the waste disposal facility.

j. Soil Backfill. The private contract organization will backfill the site with top soil and seed the site. The decision when the backfill operation will be completed will be made by the 434th CES/CEV. The post-remediation in-situ gamma measurements should provide sufficient evidence of meeting the remediation goal for the site. Otherwise, soil backfill can be completed after the final status soil samples have been analyzed.

k. Final Status Report. AFIERA will prepare a Final Status Report for the site. The report will contain a summary of the site history, characterization study results, description of the area remediated, characteristics of disposed soil, results of scanning in-situ gamma surveys, results of preliminary and final fixed in-situ gamma surveys, final status soil sampling results, and RESRAD dose predictions for the site based on the final status. A draft report will be prepared for review by the 434th CES/CEV, EPA, Indiana State Departments of Health and Environmental Management (ISDH&EM), and the AF Safety Center. A final report will be prepared based on comments from the above organizations.

l. Soil Disposal. Soil disposal activities will be described in a separate document to be prepared by the private contract organization.

m. Survey Personnel. Table 3 contains the tentative survey personnel. Personnel from the (ISDH&EM), EPA, and the 434 ARW are invited to participate.

Table 3. Survey Team Personnel.

Name	Position	Organization
Major Steven Rademacher	IERA Leader/Survey Chief	IERA/SDR, Brooks AFB TX
Capt Edward Jakes	AF Regulatory Oversight	Air Force Safety Center, Kirtland AFB NM
Mr. Brian Renaghan	Health Physicist	IERA/SDRH, Brooks AFB TX
SSgt Jeffery Compton	Health Physics Technician	IERA/SDRH, Brooks AFB TX
SSgt Darrin Lawrence	Radioanalytical Technician/Sample Control	IERA/SDRR, Brooks AFB TX

n. Instrumentation and Analytical Methods. All portable Air Force field instrumentation will be calibrated at the AFIERA Radiation Instrumentation Calibration Facility. Table 4 contains a summary of instrumentation and laboratory analytical methods.

Table 4. Instrumentation and Analytical Methods.

Measurement Type	Location	Instrumentation	Estimated Minimal Detectable Concentration
In-situ gamma (scanning)	Remediation area – 10 cm above surface	3 x 3 NaI (Tl) detector (Bicron) w/ Ludlum 2221 Ratemeter/Scaler	20 pCi g^{-1} (DU)
Surface soil samples	Surface samples from top 15 cm of soil – composite within 1 m^2 grid Waste profiling	Laboratory gamma spectroscopy – U-238 U-235	1.0 pCi g^{-1} 0.1 pCi g^{-1}
In-situ gamma (Fixed)	Selected locations in accident & back-ground regions – 10 cm above surface	3 x 3 inch NaI (Tl) detector (Bicron) w/ Ludlum 2221 Ratemeter/Scaler	6.4 pCi g^{-1} (DU)
TCLP-metals, ignit., organic volatile	Waste profiling	Laboratory	NA

5. Quality Assurance/Quality Control

a. General. Quality assurance (QA) refers to the planning, implementation, and oversight conducted to ensure the data produced can be used as intended for interpretation and decision making. QA measures that will be implemented include chain of custody controls and documentation, review of data collection procedures and documentation, and review of laboratory results. Quality Control (QC) is the system or series of activities conducted to control and measure the validity and completeness of the data produced. QC measures that will be implemented include function and radiation response checks at the beginning and end of each workday for radiation detection instrumentation and use of redundant radiation detector systems (duplicate measurements). QC measures for collection of soils included collection one set of QC samples for every ten samples of a given type (soil surface, subsurface) collected. The set of QC samples consists of the following:

- **Collocated Samples**: Collocated samples are samples collected adjacent to the routine field sample to determine local variability of the radionuclide concentration. Typically, collocated samples are collected about one-quarter to one meter away from the selected sample location. Analytical results from collocated samples can be used to assess site variation, but only in the immediate sampling area.
- **Field Replicates**: Field replicates are samples obtained from one location, homogenized, divided into separate containers, and treated as separate samples throughout the remaining sample handling and analytical processes. These samples are used to assess error associated with sample heterogeneity, sample methodology and analytical procedures.
- **Background Sample**: Background sample is a sample collected in an area where there is little or no chance of migration of the contaminants of concern. Background samples are collected from the background reference area and are considered "clean" samples. They provide a basis for comparison of contaminant concentration levels with samples collected from the site of suspected contamination.

b. Private Laboratory Samples. Ten of the final status soil samples will be split in the field lab, with one half being retained by AFIERA for analysis, and the other half being sent to Duke Engineering Services for gamma spectroscopy analysis. The Environmental Protection Agency (EPA) and State of Indiana may collect soil samples for analysis at an independent laboratory of

their choice. In this case, arrangement will be made to allow sample splits and/or collocation of sampling to meet the needs of the EPA and/or State of Indiana.

c. Data Analysis of Quality Control Samples. Quality control samples will be compared statistically to paired samples and co-located samples. For paired samples, relative percent difference will be calculated as follows:

$$\mathrm{RPD} = \frac{2\left(\mathrm{M}_1 - \mathrm{M}_2\right)}{\left(\mathrm{M}_1 - \mathrm{M}_2\right)} \mathrm{x}\,100,$$

where M_1 and M_2 are the respective sample activity concentrations. For sample groups (i.e. $n > 2$), percent coefficient of variation (% CV) will be calculated as follows:

$$\%\,\mathrm{CV} = \frac{\mu}{\sigma} \mathrm{x}\,100,$$

where μ and σ respectively are the mean and standard deviation. These indices will be used to estimate the confidence in the estimation of the final site status.

6. Health and Safety.

a. Radiation Exposure. The radiological risk presented to the work crew is small based on the activity concentration level of depleted uranium in soils from the characterization survey (Rademacher and Hoak 00). The highest depleted uranium activity concentration from this survey was 50 pCi g^{-1}, with the average in the most contaminated grid (100 m^2) being 18 pCi g^{-1}. Personnel will wear disposable gloves during collection of soil samples for the purpose of preventing cross-contamination. All survey and remediation personnel and equipment leaving the area will be frisked with an alpha scintillation detector. Eating, smoking, and drinking will be prohibited within the remediation area. Personal protective equipment (PPE) like air-purifying respirators and anti-contamination clothing will be available if unsuspected radiation hazards are uncovered. Based on the characterization survey, this appears highly unlikely. Modified level D (steel toe boots, long sleeves, and gloves) will be utilized initially. Should unanticipated conditions arise, higher levels of PPE and monitoring will be implemented at the discretion of the team chief.

b. Physical Hazards.

Terrain. The terrain in the investigation area is generally flat with irregular features that present tripping and ankle injury hazards. Personnel will be required to wear high top leather boots.

Operational Flight-Line Hazards. The remediation area is immediately adjacent to an active runway and requires restrictions on vehicle movement and personnel movements. All activities will be coordinated with the 434th ARW.

Noise. The investigation area is immediately adjacent to an active runway and is categorized as a hazardous noise area. All personnel will be issued hearing protection.

Heat Stress. All team members will be briefed on the signs and symptoms of heat stress. Fluids and sun-screen will be available at the vehicle parking area. Work rest regimes will be implemented if conditions are conducive to heat stress.

Wildlife/Insects. The remediation area may be home to biting insects, ticks, snakes, and rodents. Personnel will be wearing military battle dress uniforms that have been designed with protective features against insect bites. Insect repellent will be available to team members.

Heavy Equipment Hazards. Because heavy equipment will be used for the soil remediation activities, a hazard zone will be designated during soil removal operations. All unnecessary personnel will remain outside of the zone during these operations. The private contract organization that will operate the heavy equipment will be responsible for designation of the hazard zone.

c. Adverse Weather Conditions. Adverse weather conditions will suspend site operations because of the risks for personnel injuries and potential for dispersal of contaminated soils from high winds.

d. Medical Emergencies: If a medical emergency arises, the base fire department will be contacted at 911 or via the base radio net.

7. References.

Armstrong Laboratory, Consultative Letter, AL-CL-1992-0186, Radiological Decommissioning Survey of Selected Weapons Storage Facilities at Grissom AFB, Nov 1992.

Headquarters Air Force Safety Center, Letter from Col Burl E. Hickman to Valerie Stacy, Grissom ARB, Review of Documents Regarding 1964 Bunker Hill AFB Broken Arrow, 1996.

Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), NUREG-1575, December 97.

Rademacher, S.E., Major, Headquarters Air Force Safety Center, Kirtland AFB NM, Personal Communication, August 1999.

Rademacher, S.E., Review of the Pu-239/240 to Am-241 Activity Ratio Analysis for Work Related to Remediation of the BOMARC Missile Accident Site, Technical Report AFSC-TR-1999-0002, Air Force Safety Center, Kirtland Air Force Base, New Mexico, November 1999.

Sandia National Laboratories, *United States Nuclear Weapons Accidents*, February 1997.

United States Environmental Protection Agency, Radiation Sciences Analysis Program, Letter to Jane Smith, Indiana Department of Health, October 1996.

United States Environmental Protection Agency, Emergency Response Branch, *Draft Risk-Based Preliminary Remediation Goals for Soil Contamination at the B-58 Hustler Crash/Burial Site at Grissom Air Reserve Base, Bunker Hill, Indiana*, 1999.

United States Public Health Service – Bureau of State Services, Washington DC, Letter from D.J. Nelson Jr., to Program Director, Radiological Health, Region V, et al, Preliminary and Final Reports – DPH Broken Arrow Team, December 15, 1964.

Appendix A

Uranium Decay Series

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Appendix A

Uranium Decay Series

Table A-1: U-238 Decay Series

Isotope	Half-life	Radiation	Energy (MeV)	Percent Yield
^{238}U	4.5×10^9 y	α	4.2	75
			4.15	23
		γ	0.0496	0.07
^{234}Th	24 d	β	0.192	65
			0.100	35
		γ	0.092	4
^{234m}Pa	1.2 min	β	2.29	98
			1.53	<1
			1.25	<1
		γ	0.39	0.13
			0.817	4
^{234}U	2.5×10^5 y	α	4.77	72
			4.72	28
		γ	0.093	5

Table A-2: U-235 Decay Series

Isotope	Half-life	Radiation	Energy (MeV)	Percent Yield
^{235}U	7.1×10^8 y	α	4.32	3
			4.21	5.7
			4.58	8
			4.5	1.2
			4.4	57
			4.37	18
		γ	0.110	2.5
			0.143	11
			0.163	5
			0.185	54
			0.205	5
^{231}Th	25.64 h	β	0.302	52
			0.218	20
			0.138	22
		γ	0.026	2
			0.085	10

Appendix B

Correlation Coefficient, and Inverse Cumulative Probability Distributions for Fixed and Scanning Measurements with Portable NaI(Tl)

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Appendix B

Correlation Coefficient, and Inverse Cumulative Probability Distributions for Fixed and Scanning Measurements with Portable NaI(Tl)

Correlation Coefficient

The estimated correlation coefficient of the portable 3 x 3 NaI(Tl) instrument is based on survey and soil sampling results from the characterization study (Rademacher and Hoak 00). Two estimates are made from the data. The first, illustrated in Figure B-1, is a regression analysis of surface soil sample results and in-situ gamma measurements from discrete locations. The estimated correlation coefficient between instrument response and ^{234}Th activity concentration is 240 counts per minute (cpm) per pCi g^{-1}.

Figure B-1. Regression Analysis of Discrete Soil Sample Analysis for Th-234 and 3 x 3 NaI(Tl) Instrument Response

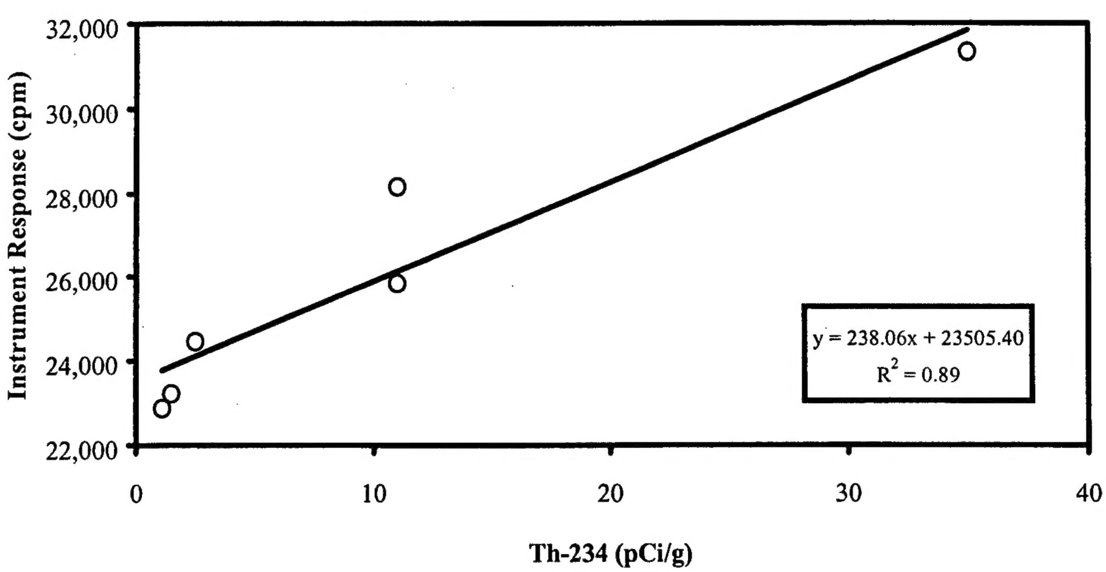


Table B provides a correlation between the composite surface soil sample analysis for the grid encompassed by 50N – 60N and 10W – 20W as shown in Figure 2. Because in-situ gamma measurements were taken on gridlines, those measurements are appropriately weighted according to measurements collected on the interior of the grid. Overall, for this analysis, the correlation coefficient between instrument response and ^{234}Th activity concentration was about 200 cpm g pCi^{-1}, about 20 % lower than that estimated by the first method. Because the value estimated by the

second method had a lower correlation coefficient, that value will be used for other calculations made in this appendix. Use of a lower correlation coefficient is conservative in that it underestimates the ability of the instrument to detect residual depleted uranium.

Table B. Correlation Coefficient between Composite Grid Soil Sample Analysis for Th-234 and 3 x 3 NaI(Tl) Instrument Measurements in Grid

	In-Situ Measurements (cpm)					
Coordinates	50 N	52N	54N	56N	58N	60N
10 W	24,509	24,173	25,033	27,328	31,481	26,239
12 W	24,394	24,577	26,520	29,985	27,990	25,041
14 W	24,760	26,413	30,374	31,507	25,735	23,596
16 W	24,573	26,453	31,324	28,158	23,770	23,203
18 W	24,408	26,638	27,429	24,442	22,861	22,714
20 W	24,687	27,000	24,058	23,203	22,696	

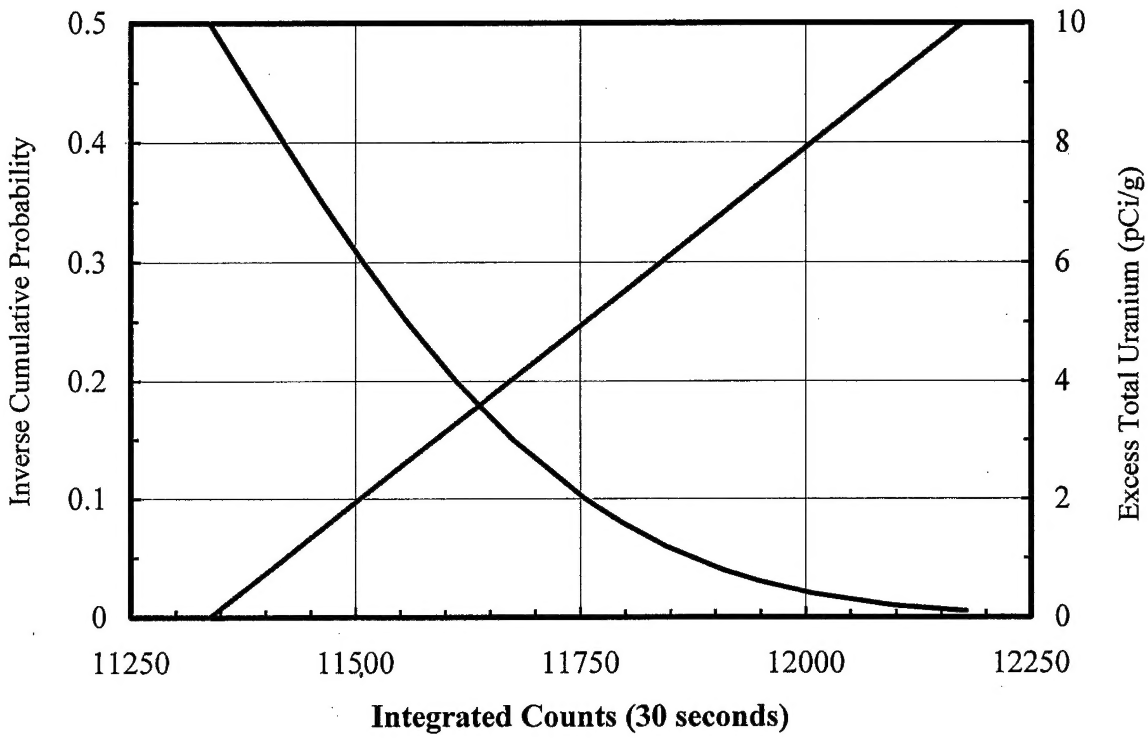
	100 % Weighting	Background Count Rate = 22,676
	50 % Weighting	Weighted Mean Count Rate = 26,338
	25 % Weighting	Net Count Rate = 3,662
		Grid Th-234 Concentration = 18 pCi/g
		Correlation Coefficient (cpm-g/pCi) = 203

Fixed In-Situ Measurements

Figure B-2 contains a plot of inverse cumulative probability and excess total uranium concentration vs. integrated counts in a 30-second count period for the portable 3 x 3 NaI(Tl). The inverse cumulative probability distribution (red line) accounts for sources of variability in the count rate of the detector for a 30-second count period from the characterization (Rademacher and Hoak 00). The excess total uranium activity concentration (green line) on the plot is based on a correlation coefficient of 200 cpm g pCi^{-1} for a depleted uranium contaminant, a background count rate of 22676 cpm, and a uranium background of 1.1 pCi g^{-1}. The plot allows selection of an action-level for fixed in-situ gamma measurements with estimated probabilities that the instrument response is due to background sources alone and mean excess uranium concentrations due to the depleted uranium contaminant. For example, at an integrated count rate of 11,750 counts per 30–second period, the probability that the instrument response is due to background alone is 10 %, with an estimated mean depleted uranium contamination level of 5 pCi g^{-1}. At the 5 % probability level, the

estimated mean depleted uranium contamination level is 6.4 pCi g^{-1}, while it is 9 pCi g^{-1} at the 1 % probability level.

Figure B-2. Inverse Cumulative Probability (Red) and Excess Total Uranium (Green) vs. Integrated Counts for 30-Second Count Period



Scanning In-Situ Measurements

Figure B-3 contains a plot of inverse cumulative probability and excess total uranium concentration vs. integrated counts for scanning measurements under the assumption that the portable meter connected to the detector integrates detector response over a two-second period. The plot is derived from the same data as Figure B-2, with the only difference being the integration period. Because the integration period is significantly lower than the 30-second integration period, discrimination of contaminated areas from natural background is more difficult. For example, at the 10 % probability level, the estimated mean depleted uranium contamination level is 16 pCi g^{-1}. At the 5 % probability level, the estimated mean depleted uranium contamination level is 20 pCi g^{-1}.

Figure B-3. Inverse Cumulative Probability (Red) and Excess Total Uranium (Green) vs. Integrated Counts for 2-Second Count Period